

Problem of model usage in mechanical engineering

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Abstract. The concept ‘model’ in mechanical engineering is analyzed. Some problems of model usage at the industrial enterprise are named: ontology of elements of difficult model system; difference between the description of the model in natural language and mathematical language; the problem of fitting objects. Design of new way of feedback between a paint robot and its operator based on the use of not only virtual, but also augmented reality, requires an appeal to the ontology of models or to philosophical discourse. The difference between model description in natural and artificial languages implies the application of a semantic approach. The problem of fitting objects during the model testing in mechanical engineering can be solved during testing. The authors argue that the use of an interdisciplinary approach in comprehending complex model systems, taking into account virtual and augmented realities, allows us to clarify the conditions for using virtual 3D models in mechanical engineering.

1. Introduction

The authors of the article tried to approach the analysis of the problem of models’ usage in mechanical engineering as part of an interdisciplinary approach in terms of mechanical engineering technology and philosophy. Science is already acquainted to similar approaches, when scientists or engineers in alliance with philosophers researched real models [1], fiction models [2] and complex model systems [3, 4]. The problems emerging during usage of real and fiction models were named in these researches:

- composition, genesis, ontology of elements of difficult model system (virtual, augmented realities);
- the difference between description of the model in natural language and mathematical language;
- the problem of description – is object fitting.

Similar research is being carried out for the first time in Russia.

An industrial leader (leader of steel production plant), who shall approve project, is provided with preliminary information on design features of a paint robot. He understands that during the solving of specific problem of painting of bulk metal structures, complicated technical, organizational and other problems arise, for the solution of which he invites research engineers. Let us assume that engineers are designing a new way to establish feedback of the robot itself and its operator, based on the use of not only virtual, but also augmented reality. Imagine that a team of research engineers working on the problem of using a paint robot in the manufacture of metal structures creates a project in the form of a set of proposals, graphs, drawings, sketches expressing a certain content of the model. In this case, the



engineers will develop a complex fictional model system, the interpretation of which requires philosophical discourse, which means an appeal to the ontology of models.

2. Methods

2.1 Usage of models in mechanical engineering

During the real simulation of manufacturing system within one technological operation or the whole technological process searching of all combinations of existing factors and selection of the best (optimized) variant of combinations (treatment conditions, tool parameters, part material properties, etc.) take place.

However, a change of each factor even on two levels leads to the need to carry out approximately 40 thousand tests only for one technological operation (there can be several tens of operations in a technological cycle). It's more comfortable to study system based on the mathematical model of this system which takes into account a factor impact on objective function [5].

For example, a production system optimization model may have the following form

$$F(x_i) \Rightarrow \text{extremum}$$

where $F(x_i)$ is dependence of objective function on factors x_i . In this case, limiting parameter system is applicable

$$\{f_j(x_i) \leq C_j,$$

where $f_j(x_i)$ is a function which describes dependence of j limiting parameter on factor x_i , C_j is a constant value.

Model can be set in the form of polynomial of n-power, power dependence, a Fourier series, etc. Generally, such model is a mathematical expression without physical meaning. The degree of complexity (simplicity) of the model is determined by the level of its detail, which depends on accepted assumptions and suppositions. The main feature of the model is representativeness (adequacy) to the process which it describes. In real conditions, the model parameters are unstable; their changes are random and, as a rule, are not controlled.

2.2. Ontology models

A discussion of the composition and genesis of complex model systems raises a metaphysical question: what are models? In philosophy, it is customary to distinguish between descriptions of models, types of descriptions that appear in scientific papers, textbooks and diagrams, and the described model systems: ideal pendulums, systems of rational self-serving agents, or endless animal populations. There are metaphysical puzzles in model systems since there are no frictionless pendulum components, absolutely rational, selfish agents or endless animal populations. In recent times, there is growing interest to the idea that model descriptions shall be considered as similar to fiction and model systems should be considered akin to fictional characters. Imagination is the power in the particular context of usage.

There are solid reasons for such approach [6]. Firstly, though there are no any specific objects, which would correspond to the descriptions in the fictional stories or descriptions of scientific models, we have an ability to express truth or falseness on model systems. Secondly, developers of scientific models often relate to them particularly which suggests strong analogy with usual fiction [7]. A model consists of the model description and model content and they are separate entities that only together make up specific model. The description of the model is a set of linguistic and mathematic symbols which prescribe to imagine something specific. The mathematical equations that make up the description of the model is a sequence of mathematical symbols that does not specify any concrete truths until it is interpreted as a description of the state of the model, that is, until the variables in the equation are interpreted as meaningful for certain objects.

The description of the model and the content of the model can differ from one another. For example, model description can include not only mathematical symbols, which are usually used in different contexts, but also linguistic symbols, which can change without model content alteration: one type of description of paint robot is in English and another one is in Chinese.

A simplified understanding of reality as model denotatum does not allow for creating a multi-purpose model theory applicable in any cases. The other way to solve the problem of connection of model and reality lies in analogy of the model with sentence or text within the framework of the semantic approach. In this case, philosophers emphasize the importance of model description in natural and artificial languages. The semantic approach allows us to determine the conditions for the truth of the model, since you cannot know something about something that is not true. This raises many questions regarding the nature of knowledge, the representation of knowledge obtained through modeling on the target system. The epistemic justification that can be obtained by assessing the truth of models includes the evidence presented by the model itself. However, the conditions for the validity of comparing the model with the conditions of an industrial enterprise are limited by the requirement of linking the characteristics of the model and the real target system.

Sometimes the semantic approach is insufficient to explain those properties of the target system that are eliminated as immaterial or uncontrollable. The most difficult to explain and, at the same time, very controversial is the exclusion of some observations or measurements during experiments in the practical implementation of the model. Later, such actions or engineers may be construed as an attempt to fake the results of experiments.

If we consider the description of the model as its essence, inevitably there will be an absurd conclusion that any small change in the description of the model leads to a new model. The problem of the difference between the description of a phenomenon (model) in a natural language and a mathematical language in philosophy is solved as the relationship between linguistic expressions and designates (R Carnap). It should be noted that W. Quine tried to solve this problem by the requirement of mutual translatability [8], S. Psillos – by indicating the identity of the truth conditions [9], A. Thomasson – by using the concept of abstract artifact [10].

The most complex ontology arises when designing fictional models with elements of virtual or augmented reality, to which no objects of the real world correspond. Here, as shown by F. Salis and R. Frigg, it is crucial whether these components of the model designate a certain nominal entity or whether they are specific concepts [11]. The idea of a model as a possible world allows you to go into the space of modal fictionalism [12]. If the conclusion about the possibility of correspondence between the model and the target system is made regardless of the content of the original fiction, no matter what fiction is used, he must recognize the independence of modal truth [13, 14]. The content of fiction, of course, is associated with the idea of the boundaries of a possible world, but to a lesser extent. The point is that, as it is impossible to imagine a possible world with any characteristics, it is impossible to imagine a model with any properties that are in no way connected with any relationship with the target system.

An engineer can imagine the properties of model systems if and only if they meet the real requirements in the description of the model and the principles of generating its content. In order to predict the significant properties of the target system, he needs to move from a state of imagination to reality.

3. Results: paint robot model

To avoid the usual contradictions, a model shall necessarily describe specific target system [15]. There is a problem of paint application to the finished product at the enterprises manufacturing welded steel structures (erection trusses, bridge spans, etc.). During the application of coating, as a rule, pneumatic spraying of the paintwork composition is used, as the most productive method. The products being painted are very complicated spatial structures. Since the coating process at enterprises is difficult, pneumatic spraying of the composition is done manually. This creates an unfavorable environmental situation for the operator producing the paint. One of the variants of automating the process is usage of

robots. However, robot shall be preprogrammed for performing movement of manipulator with the spray gun along a spatially complex path. Programming with a large product range is a laborious and expensive process. A simpler engineering solution is remote control of the robot. Operator is removed from the paint zone and controls the robot through video camera mounted on the robot. Disadvantage of the scheme is pollution of camcorder lens by spray products. The possible solution of this problem is to create a virtual model of the product being painted. Initially, the robot scans the metal structure, as a result of which, virtual 3D model of the product, some virtual reality (VR) is created in the memory of control computer. Then operator controls the robot in this virtual reality with the use of VR Box. The real robot repeats the movements of the virtual robot.

Model description is possible only in natural language or mathematical language. When using natural language it is necessary to have detailed description of the whole system, its separate elements, type of interaction of elements and their static and dynamic parameters.

For example, as follows, the position of each robot link in space is determined by the coordinate system connected to this link. The position of the coordinate system associated with the link relative to the inertial system is determined by radius-vector of its beginning which has three independent projections and three angles between the corresponding axes of the system. In general, each link of the robot represents a mechanical system with six degrees of freedom. If there are some connections which limit movements of the body, the number of degrees of freedom decreases. Since manipulation systems represent open kinematic chain consisting of rigid (absolutely firm) links interconnected with kinematic pairs of the fifth class with one degree of freedom, each link of such manipulation system, except for the last one, constitutes two kinematic pairs. For that reason, each link is connected with two coordinate systems located in the centers of kinematic pairs of this link. Such description of the robot system and its each link can take more than one page of the text.

For practical purposes it is more convenient to use mathematical model which allows for planning of program trajectory of movement and defining the range of possible deviations (dynamic errors) of manipulator systems from this trajectory caused by elastic compliance of links. Motion equations used to simulate the dynamic of manipulation system, depending on the method of compiling of these equations, can be represented as mathematical model

$$M(q,d)\ddot{q} + \dot{q}^T C(q,d)\dot{q} + g(q,d) = P$$

$M(q, d)$ is matrix ($n \times n$) of inertial characteristics of system; $C(q, d)$ is matrix ($n \times n \times n$) of centrifugal and Coriolis effects; $g(q, d)$ is gravitational vector of the size n ; $q = [q_1 q_2 \dots q_n]^T$ is generalized coordinates vector; d is vector containing geometric and dynamic parameters of the system.

In any case, when describing, the model will differ from the original for the following reasons.

Firstly, due to the complexity of any described system, model is constructed under certain assumptions. Model is a simplified copy of the original. Simplification is possible to such an extent until simulation error is within the prescribed limits. Therefore, the model does not reflect all but only the essential characteristics of the original.

Secondly, the real mechanism (robot) has some elastic flexibility of the manipulation system links. Therefore, static and dynamic deformations and oscillations of system links appear. These characteristics depend on many factors (geometric link sizes, gaps in moving couplings and joints, dynamic characteristics of drives, etc.) which values for specific mechanism are random.

As a result, in order to more accurately describe the dynamics of the manipulation systems with rigid links and elastic joints, to increase of dynamic accuracy of their movements, it becomes necessary to correct (fit) the general model for a specific mechanism (robot) – change coefficients, introduce new elements, etc.

4. Conclusion

The creation of 3D models of products when they are painted with a paint robot at an industrial enterprise is an example of fictional models. With the philosophical understanding of the ontology of real, fictional models and complex model systems, numerous problems arise. Authors made an attempt to discover the following: ontology of elements of difficult model system (virtual, augmented realities); the difference between the description of the model in natural language and mathematical language; the problem of description is fitting objects.

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